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Some Brightness Variations in the North Sky and the Horizon Sky and Sea Measured During Daylight Hours

ELSIE F. DUPRE AND GORDON L. STAMM

Optical Warfare Branch
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SOME BRIGHTNESS VARIATIONS IN THE NORTH SKY AND THE HORIZON SKY AND SEA MEASURED DURING DAYLIGHT HOURS

INTRODUCTION

Light sources viewed at a distance through the atmosphere in daylight are generally visible to an observer because they are seen to be brighter than the backgrounds against which they are viewed. When they are brighter, and thus visible, how well and how far away they can be seen depend among other things on the brightness of the background relative to the source brightness. For example, a source of a given brightness cannot be seen nearly as well against a background of a brightness close to its own as against a much darker background. The maximum distance at which a source of a given brightness is visible against sky backgrounds of various brightnesses has been investigated and the results put forth in a series of nomograms which have been published by Duntley (1).

In the outdoor world of natural backgrounds—the sky, sea, trees, and others—the brightnesses that prevail vary with existing conditions, such as the position of the sun in the sky and the cloud cover. With the variations that occur the visibility of a distant source under observation may be subject to change accordingly. The change may be only slight or it could be drastic, as when a source becomes invisible when the brightness of its background becomes as great as its own.

The dependence of source visibility on background brightness is an important consideration in optical communications. It may even be critical, as when a communications system is operating near its threshold and the background brightness suddenly increases; in this situation the signal light from the source may cease to be visible and communications may be quickly wiped out. This is true for electro-optical as well as eyeball receivers, for in an electro-optical receiver an increase in background brightness often brings about an increase in receiver noise in which the source signal may then be undetectable.

In the naval environment at sea the sky and/or sea are the backgrounds against which signal lights are viewed. For ship-to-ship signaling, as is done with the present Navy Morse-code, blinker-light signaling system, the part of the sky and sea viewed is at the horizon, but for ship-to-aircraft signaling any part of the sky or sea may be viewed.

Variations that occur in the brightness of the sky and sea may come about in different ways. For example, in viewing a distant light source, a small, bright white cloud may drift in back of the light and temporarily cover the darker blue sky which was the background against which the light was viewed before the cloud came into view. Or a receiver mounted aboard a rocking ship and pointed toward another ship may alternately view the sea and the brighter sky at the horizon. A more gradual, longer-term kind of variation which covers a wide range of brightness levels for both the sky and sea is the one that occurs at twilight.

Very little information has been found by the authors on the brightness variations of the sky and horizon sea except those that occur with the change in the sun's zenith angle, mainly at twilight (2-8). Most brightness measurements have been limited to the clear, cloudless sky, although some have been made under uniformly cloudy and hazy conditions; many of the measurements have been made on the zenith sky only. Brightness variations found across the sky due to cloud formations have received practically no attention,

whereas variations across the sky-sea horizon have received only a little more (9,10). Recently at the Naval Research Laboratory, Knestrick and Curcio measured visible and ultraviolet spectral radiance of the horizon sky (11,12).

In view of the paucity of information found on brightness variations of the sky and horizon sea, the authors set about to obtain some brightness data on their own, which are presented in this report. Although these data are not recent, they are reported here to help those who are interested, since a complete discussion has not been printed heretofore. The data were obtained from measurements made on the north sky, at a fixed point on one occasion and on the sky-sea horizon at one fixed point above and another below the southern horizon on another occasion. Both sets of measurements extended throughout the day from around sunrise to sunset. During the afternoon of the north sky measurements, clouds drifted across the field of view of the measuring photometer and also over the sun. In the horizon measurements the vertically and horizontally polarized components of horizon brightness were also measured.

BRIGHTNESS VARIATIONS IN THE NORTH SKY

The brightness of the north sky was obtained by recording its luminance continuously from 1 hour before sunrise to 1 hour after sunset at Washington, D.C., on June 4, 1964. The point in the sky measured was due north and about 60 deg from the zenith. The day was sunny, warm, and dry with clear skies prevailing until noon when clouds began to form. In the afternoon clouds drifted over both the sun and the point of the sky measured.

The measurements were made with a photoelectric photometer (Spectra Brightness Spot Meter, Model UB-1/2) mounted on a tripod on the roof of a four-story building. The photometer was equipped with a photopic filter which produced for it a relative spectral sensitivity close to that of the light-adapted eye. Tests showed that it gave correct readings in foot-lambert units when these luminances were produced by unpolarized light of 2854° Kelvin color temperature. The photometer field of view was 0.5 deg.

The recordings made of luminances were in the form of traces made with a recording milliammeter that was connected to the measuring photometer through an amplifier. Trace readings were related to luminance values in foot-lamberts (fL) by means of a calibration curve obtained by taking readings of known luminances on a magnesium oxide plaque illuminated by a standard lamp.

The luminances measured are given by the curve in Fig. 1. In plotting the curve, readings were taken from the recorder trace every 3 min when the trace was uneventful and every 1 min or less when luminance changes occurred. Luminances are plotted logarithmically because of their great dynamic range.

As seen in Fig. 1, the luminance increased rapidly and steadily during the clear morning twilight, covering an increase from 10^{-2} to 10^{3} fL in about 2 hours' time. By the time the sun had risen to about 13 deg above the horizon at 0600, the luminance leveled off, finally reaching a value of 2000 fL for the blue sky at about 1100. Then, clouds began to drift over both the sun and the point of the sky measured causing luminance fluctuations all afternoon with values varying between about 1500 and 3000 fL until the sun dropped to about 21 deg above the horizon at 1730. As evening twilight set in, the luminance began to decrease rapidly at about the same rate as it had increased during morning twilight. During this period of rapid decrease, there were still luminance fluctuations due to passing clouds, but they were difficult to measure because of the rapidity of the decrease and therefore do not show up in the curve of Fig. 1.

Some of the conditions which existed in the sky during the measurements are indicated by letters placed along the curve in Fig. 1. During the early morning, the sky was clear with some morning haze (a). Later in the morning the clear sky turned quite blue, and the sun shone brightly (b). Approaching noon, wisps of clouds began to appear (c) which turned into full cloud formations in the afternoon. Times when clouds were within

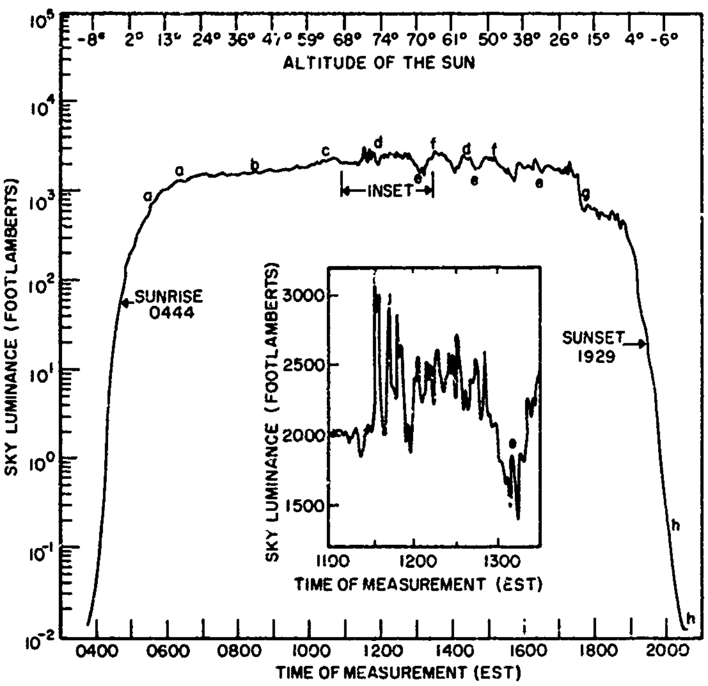

Fig. 1 - Luminances measured at a point in the north sky during the daylight hours. a - Clear sky, morning haze; b - Sky clear and blue, sun out; c - Sunny and clear, wisp of cloud; d - Clouds in view of photometer; e - Sun behind clouds; f - Sun out; g - Sky uniform, dark blue; and h - Lights turned on in city below.

the field of view of the photometer, when the sun was behind clouds, and when the sun was out are indicated by d, e, and f, respectively. Around 1730 (g) the sky was uniform and dark blue, and finally, at the onset of night lights were turned on in the city below (h).

The details of the nature and extent of luminance fluctuations due to clouds are not exhibited too clearly in the complete curve of Fig. 1 because of the logarithmic plot of luminance and the compression of the time scale. A section of the curve extending from 1100 to 1330 is therefore magnified in the inset of Fig. 1 with luminance plotted linearly and the time scale expanded by 2-1/2 compared with the complete curve. In the inset curve the sharp peak at (i) corresponds to the passage of a white cloud within the field of view of the photometer for a period of about 4 min when the sun was out. Immediately after this cloud passed by, another one (j) which was less bright came into the field of view for a shorter time, and thereafter, other clouds passed through the field in continuous succession. The relatively broad dip in the curve at (e) corresponds to the obscuration of the sun by a cloud; while the sun was obscured, other clouds passed within the field of the photometer and caused the spikes in the curve at (e). Whenever clouds passed within the photometer field, the luminance increased from that of the blue sky. For most clouds the increase was to about 2500 fL the brightest cloud having had a luminance of 3000 fL. Whenever a cloud obscured the sun, the luminance of the blue sky decreased to about 1500 fL. In some instances a cloud did not completely fill the photometer field.

The inset curve of Fig. 1 still does not show the full structure of the luminance fluctuations found during the passage of clouds. To show an example of the full structure, a section of the original recorder trace of the photometer corresponding to the spike of the inset curve at (i) is shown in Fig. 2. The trace section runs on for 4-1/2 min, each

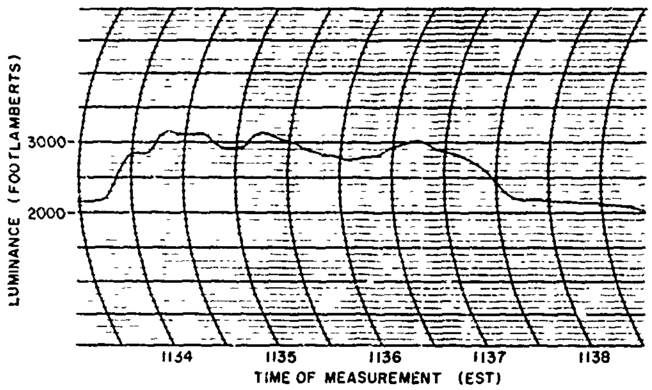

Fig. 2 - A section of original photometer trace showing full detail of luminance fluctuations during the passage of a cloud

abscissa division representing 1/2 min. This section, obtained during the passage of a white cloud, shows the cloud to have been nonuniformly bright with brightness variations extending between 2750 and 3160 fL. As the cloud entered the field of view of the photometer, the luminance reading changed rather quickly from 2150 to 2850 fL within 15 sec. As the cloud drifted by, the luminance changes were less but sometimes they occurred in a shorter period of time, some as short as 10 secs or so. Different clouds, of course, produced different trace structures, as indicated by the inset curve of Fig. 1, yet many of the cloud traces were quite similar.

BRIGHTNESS VARIATIONS AT THE SKY-SEA HORIZON

The brightness of the sky and sea close to the horizon was obtained from luminance measurements made from the shore of the Chesapeake Bay during an entire day from around sunrise to sunset on a clear, cold winter day (Jan. 18, 1966). The part of the horizon measured was where the sky and the Bay (the sea) met, which was in a direction south southeast (154 degrees azimuth angle from north) from the measurement site at the Chesapeake Bay Division of the Naval Research Laboratory. Atmospheric conditions were such as to produce a clearly discernible horizon all day long with the visual range varying between 8 and 12 mi. The wind blew from the northwest at 6 to 8 knots in the morning and changed to westward in the afternoon increasing to 14 knots at 1600.

A view of the horizon region measured is shown in the two photographs of Fig. 3, one taken with, and the other without, the sun's glitter pattern present on the water. The areas of the sky and sea measured are denoted by the circles located just to the right of the wooden platform shown, which provided a good reference point for pointing the photometer. In the pointing of the photometer the position of its 0.5-degree field of view was adjusted manually in such a way that for sky measurements the lower edge of the field almost touched the horizon and for sea measurements the upper edge did likewise. The photometer was located 13 ft above the water level of the Bay at the edge of the shore, which resulted in a line-of-sight distance to the horizon of 4.3 n. mi., as indicated in Fig. 4.

The procedure of measurement followed a definite sequence. Photometer readings were made in order: on the sky (a) directly and with a (b) vertical and (c) horizontal polarizing filter in the field of view and then followed three readings of the same type on

(a) (b)

Fig. 3 - Photographs of the sky-sea horizon region where luminance measurements were made; (a) With the sun's glitter pattern present—sea brighter than sky; (b) No sun glitter—sky brighter than sea

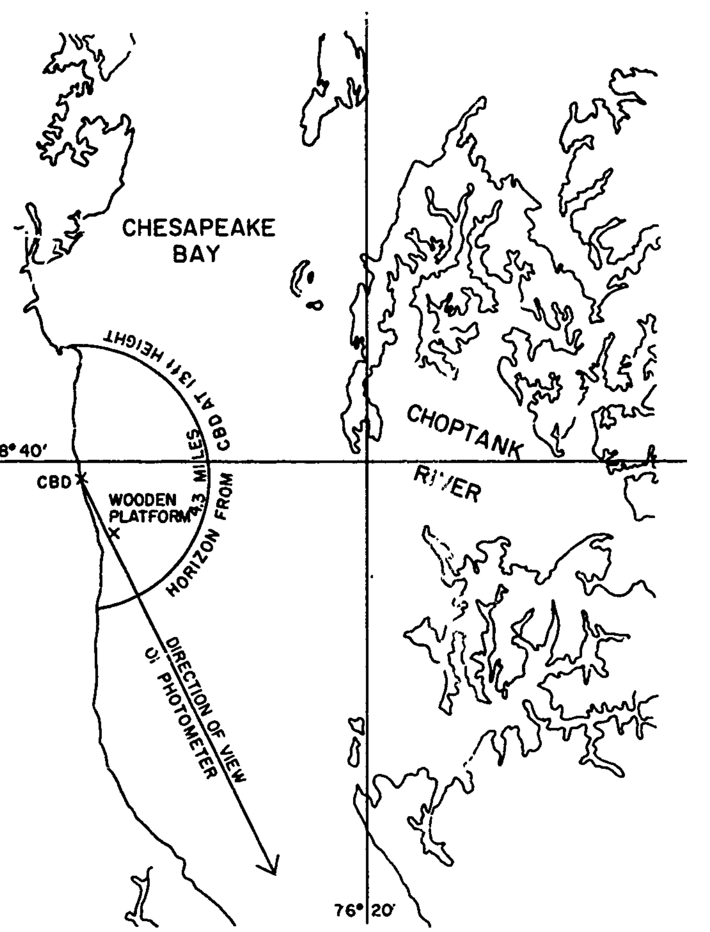

Fig. 4 - A sketch of the Chesapeake Bay area indicating the range of the sky-sea horizon observed from the shore at a height of 13 feet

the sea. The six readings were made as quickly as possible at 15 min intervals throughout the day. This procedure worked well except, perhaps, when luminance changes were rapid, e.g., around the time when the sun's glitter pattern came within the photometer field of view.

The photometer had a telescopic viewing system, which permitted the operator to see the field being measured, and a "straight-through" optical system, which made the photometer equally sensitive to light of any polarization and to unpolarized light. The latter feature was required since some of the measurements were made through the polarizing filters mentioned above. These filters were located in a turret in the photometer and could be rotated into the field of view as desired.

In tests on a source of unpolarized light, it was found that with the vertical and horizontal polarizing filters in the field of view, photometer readings were 51 and 53 percent, respectively, of the reading with no polarizer. In this report luminances for vertically and horizontally polarized light are given as they were read on the photometer with the appropriate polarizing filter in place. A calibration was made on the photometer just before the measurements to assure that its readings were in the luminance units of footlamberts. As a further check on the readings obtained, a second photometer, identical to the one already described, was set up to continuously monitor the sky luminance all during the measurements. This photometer gave readings that agreed well with the sky readings of the first photometer.

Luminance data obtained for the sky and sea are plotted in the curves of Fig. 5a and b, respectively. In each figure three curves are shown: one for direct readings (no polarizing filter used) and the other two for readings taken through the vertical and horizontal polarizing filters. The overall shape of the curves for the sea match those for the sky quite well except at the time of the sun's glitter pattern. This would be expected since the light of the sea is composed of reflected skylight except in the glitter pattern when it is reflected sunlight. Both sky and sea luminance increased rapidly in the morning around sunrise until the sun was about 13° above the horizon. Thereafter, the rate of increase gradually lessened until the luminance reached a maximum when the sun was about in line with the photometer and the point of the sky and sea. This alignment resulted in the sun's glitter pattern on the water in the direction of measurement. The total luminance increase in the morning covered six orders of magnitude from about 10^{-2} to 10^{4} fL. After the sun passed through the alignment position, the luminance decreased gradually during midday and the afternoon until the sun was about 12° above the horizon, one hour before sunset. This decrease amounted to about one order of magnitude to 10^{3} fL. As evening twilight set in, the decrease became more and more rapid until it was at about the same rate as the morning increase. Measurements were started in the morning and ended in the evening when luminances were still increasing and decreasing, respectively, at a rapid rate. Thus, the data of Fig. 5 do not show the low luminances of the nighttime horizon sky and sea.

For most of the day the sky luminance was greater than the sea luminance, whether or not measured through a polarizing filter. This is shown clearly by the curves in Fig. 6 where the ratio sky to sea luminance is seen to be greater than one over most of the day. Exceptions to this occurred in the early morning and again during the time of the sun's glitter pattern. There is a definite trend of increasing ratio with the rapid increase of light level in the morning and decreasing ratio with the rapid decrease of light level in the late afternoon. It is thus seen that with rapidly increasing or decreasing light levels, the sky luminance increased or decreased, respectively, at a faster rate than the sea luminance.

The value of the sky-sea luminance ratio measured directly without a polarizing filter was 0.4 (sky about half as bright as sea) at the time of earliest measurement in the morning and gradually increased, except for the time of the sun's glitter pattern, to a

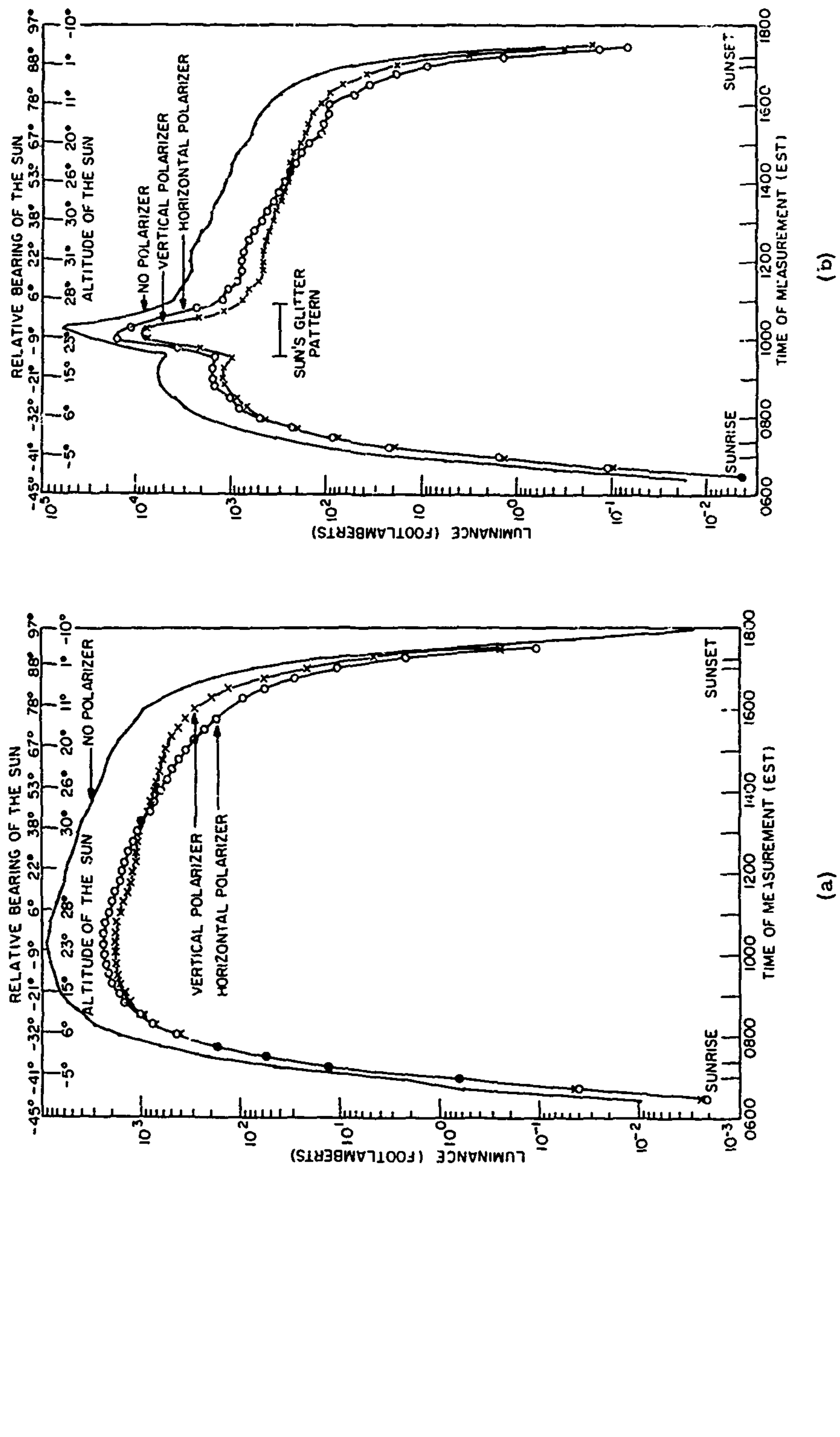

Fig. 5 - Luminance of the horizon sky (a) and sea (b) during the daylight hours

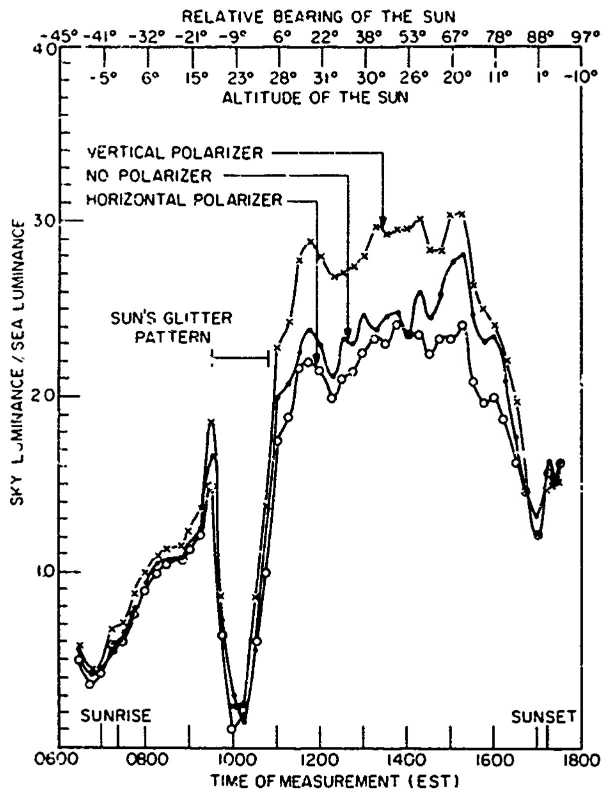

Fig. 6 - Ratios of sky luminance to sea luminance with and without a vertical and a horizontal polarizing filter in the photometer field of view

maximum value of 2.8 (sky almost three times brighter than sea) in the afternoon about 2 hours before sunset. At noon when the sun was at its highest point in the sky, the ratio was about 2. After reaching its maximum value, it decreased rather rapidly as sunset approached and the light level decreased, but it never went below one (sea brighter than sky) before measurements were stopped. The ratio reached its lowest value, 0.1 (sea 10 times brighter than sky) just about the time when the sun's glitter pattern was the brightest and remained below one during most of the time of the glitter pattern. An idea of the relative brightness appearance of the sky and sea both in the presence of the glitter pattern and in its absence can be gotten by inspecting Figs. 3a and b, respectively.

The light from sky and sea was not greatly polarized in either the vertical or horizontal directions. It was, though, somewhat more strongly polarized in the horizontal direction in the morning and early afternoon and in the vertical direction in the late afternoon for both sky and sea (see Fig. 5). The switchover from stronger horizontal to stronger vertical polarization occurred later in the afternoon by about one hour for the sea (1400) than for the sky (1300), as shown by the crossover points of the vertical and horizontal polarizer curves in Fig. 5a and b.

The ratio of luminance measured through the horizontal polarizing filter to that measured through the vertical polarizer is shown for both sky and sea in Fig. 7. For the sky the ratio was greatest just before noon (the time of the sun's highest elevation in the sky) when it remained above 1.3 for a period of more than one hour, and for the sea it was

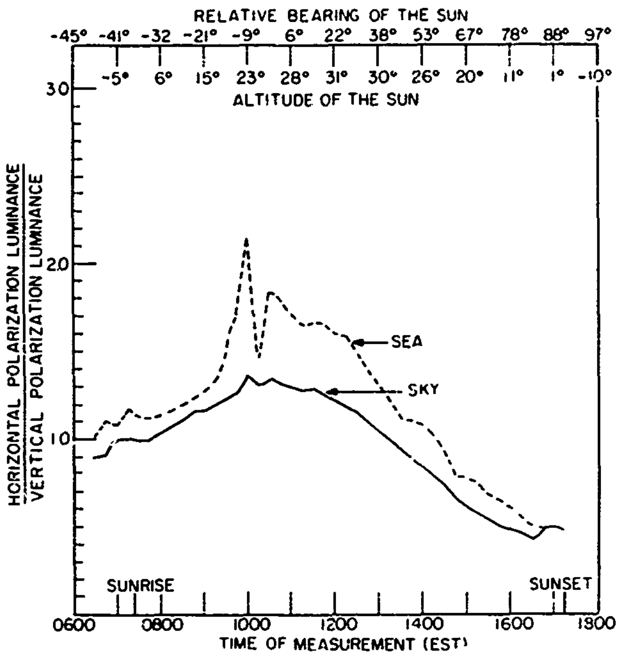

Fig. 7 - Ratios of luminances measured through a horizontal and a vertical polarizing filter for the sky and sea

greatest at the time of the sun's glitter pattern when it peaked to a value of 2.1. It reached its lowest value for both sky and sea, 0.4, just before sunset near the end of the measurements, having decreased all afternoon from its maximum midday values.

It is seen in Fig. 6 that, with the use of polarizing filters, the values obtained for the ratio of sky-to-sea luminance are different from the values obtained with no filter. With a vertical polarizer the values are generally higher and with a horizontal polarizer they are somewhat lower than with no filter. For example, during midday, ratios of about 2.9 were obtained with the vertical polarizer, 2.2 with the horizontal polarizer, and 2.4 with no polarizer.

DISCUSSION

In the results of the measurements reported on here, data are given for brightness variations found in the sky and in the sea horizon due to three causes; changing sun position, clouds, and area of measurement above and below the sky-sea horizon. The extent of the variations measured was both great, as in the sky and sea at twilight, and small, as across the sky-sea horizon. The variations were also both of a gradually and continuously changing kind as in the clear sky at twilight, and of a fluctuating kind, as in the sky during the passage of clouds.

For brightness variations caused by changing sun position, the greatest variations, of course, were found during morning and evening twilight when the sun was rising and setting, respectively. A change of about five orders of magnitude (between about 10^{-2} and 10^{3} fL) was covered in the measurements for the north sky and of about six orders of magnitude (between about 10^{-2} and 10^{4} fL) was covered for the horizon sky and sea. The full extent of the twilight change was not covered, for measurements were not made into

the darkness of night. The rate of change of luminance was found to be about logarithmic over much of the time of twilight for both the north sky and the horizon, sky and sea as can be seen by the nearly straight-line increasing and decreasing parts of the curves in the logarithmic plots of Figs. 1 and 5. The greatest rate of change found was during this logarithmically changing part of twilight when rates as low as a factor of 2 change to as much as a factor of 4.5 change in a 5-min interval were found depending on the measurement situation (sky, sea, and atmospheric conditions).

Brightness variations due to changing sun position were also found around the time of measurement on the sun's glitter pattern on the sea. The glitter was found to be about 15 times brighter than the sea in the absence of glitter. As the glitter came into view, the sea brightness increased for about half an hour, then reached a peak, and finally decreased for about half an hour until it was no longer within the field of view (see Fig. 5b). The rate of change during the increase and decrease was by a factor of about 2 per 5-min interval.

Brightness variations found due to cloud formations covered a maximum change of about a factor of 2 (3000 to 1500 fL) for white clouds floating across the clear, blue north sky. The highest brightnesses were measured on clouds when the sun was out and the lowest on the blue sky when the sun was covered by a cloud. When the sun was out, the brightness of the blue sky was 2000 fL. The rate of change of brightness was rather rapid for clouds floating into the field of view; this, of course, depended on the velocity of cloud movement and the size of the field measured. Brightness variations within a cloud itself amounted to at most a 10-percent change.

Brightness variations found across the sky-sea horizon varied with the time of day. Most of the time the sky was brighter than the sea, the maximum sky-to-sea brightness ratio being found to be on the average about 2.5 during about 5 hours of late morning and the afternoon. During morning twilight, the sky brightness increased at a faster rate than the sea brightness, and during evening twilight, the reverse occurred. There were two times when the sea was found to brighter than the sky: in the morning around the time of sunrise and at the time of the sun's glitter pattern. At the former time the sea was at most about twice as bright as the sky, and at the latter time it was at most 10 times brighter.

Viewing the horizon sky and sea through vertical and horizontal polarizing filters generally changed the relative brightnesses of sky and sea somewhat. The vertical polarizer made the ratio of sky-to-sea brightness higher compared with no polarizer (the 2.4 times ratio given above was raised to 2.9 using a vertical polarizer), and the horizontal polarizer made it slightly lower.

The data presented in this report exemplify the extent of brightness variations found at the places measured and show that changes in brightness of several orders of magnitude are involved. Such large changes might indeed affect the visibility of distant signal lights or the detection capability of optical communications receivers. Even some of the smaller magnitude changes, as between a cloud and the blue sky, could conceivably have an effect on the reception of optical signals. The data presented, of course, cover only a few situations and conditions, yet they are indicative of the brightness behavior of the places measured. To obtain a more general picture of brightness variations would require the combination of judiciously chosen experimental data and complex theoretical studies.

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